ON LUNAR OPPOSITION SPIKE OBSERVED BY CLEMENTINE.

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Introduction. Among a great deal of the lunar surface images taken by the UVVIS camera during Clementine mission there are some images with the zero phase angle point. It gives a unique possibility to study so-called opposition spike, that is anomalous increase of surface brightness at the smallest phase angles. This phenomenon is seen in the images as a diffuse brightened spot around the zero phase angle point [1]. As an example, **Fig. 1** shows the UVVIS frame LUC2275J.167 (900 nm filter). The frame is centered at 1.3^0 N 3.9^0 E and includes North-East part of Sinus Medii strongly brightened by the ray system of crater Triesnecker, and small part of adjacent highland.

To obtain the dependence of brightness on phase angle (so-called phase curve) one needs to compare the brightness at small phases with brightness of the same site under usual observation / illumination conditions. Unfortunately there are few UVVIS frames where direct comparison is possible. In [1] the dependence of brightness on local phase angles was averaged over a number of frames to diminish variations of the scene albedo. We propose another way to extract the phase curves from the Clementine UVVIS images.

Data processing. Our method is based on subtraction of two images taken consequently in different filters. Due to spacecraft motion the zero phase angle point moved on the surface. After the subtraction the albedo pattern is practically quenched, but the opposition spot is not quenched completely due to the shift of the phase angle pattern. We use the fact that brightness variation due to color difference is smaller than the variation due to the shift of the zero phase point. As an example, **Fig. 2** shows highly contrasted result of subtraction of the frame LUD2271J.167 (950 nm filter) from the frame shown in Fig. 1. The difference in the local phase angle for any point in this image does not exceed 0.2^0. Of course, before the subtraction the images were calibrated and carefully superimposed. We applied the calibration procedure developed by C. Pieters and colleagues at Brown University. Knowing the phase angle in each point of both images we obtained the derivative of the phase curve in each point of the frame. Then we averaged the derivative over all points with the same phase angle. Integration of the derivative gave the phase curve.

Results. Solid line in **Fig. 3** demonstrates the result for the frame shown in Fig. 1. Dashed line in Fig. 3 shows the phase curve derived with the same technique from the frames LUD3742J.150 and LUC3746J.150 centered at 1.4^0N 48.7^0E. This site is located in Mare Fecunditatis. The scene has much lower albedo than the area in Sinus Medii shown in Fig. 1. The phase curves in Fig. 3 are normalized by brightness at the phase angle of 1^0.

Typical values of the opposition spike amplitude measured with our method in phase angle range of $0.2^0…1.6^0$ agrees with the measurements in [1] made with the method of global averaging. The opposition spike on the Moon is not as sharp and high, as observed for some bright atmosphereless bodies.

Bright material in Sinus Medii demonstrates much stronger opposition spike than dark material in

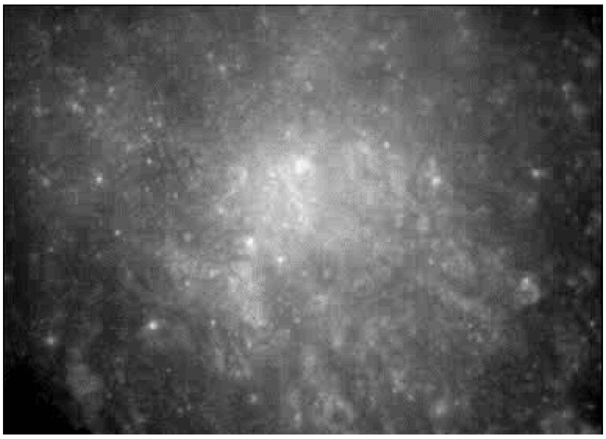

Fig. 1

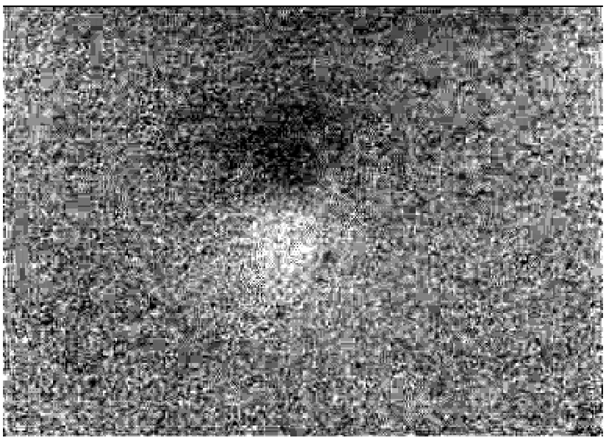

Fig. 2

Mare Fecunditatis (Fig. 3). This observation agrees with general difference between opposition spike amplitude in maria and highlands noted in [1].

The phase curves (Fig. 3) tend to level at phase angles less than 0.5^0. This effect is due to finite angular dimension of the Solar disk. It was analyzed in [2].

Discussion of the method and future work. Our method gives the phase curve in the range $0.2^0 \ldots 1.5^0$ with higher accuracy than the method of global average used in [1]. Our method uses only one frame (or even part of it), that is why it can be effectively applied to study the opposition spike for different terrains. This work is in progress now.

In [1] the opposition spike found to be 3…4 % smaller in infrared than in the visible. This difference is at the edge of result accuracy. Our method hardly can improve accuracy of wavelength dependence estimation.

Our method cannot be used for phase angles smaller than 0.1^0. The method of global average [1] gives estimations of phase curve for the smallest phase angles, but with very low accuracy.

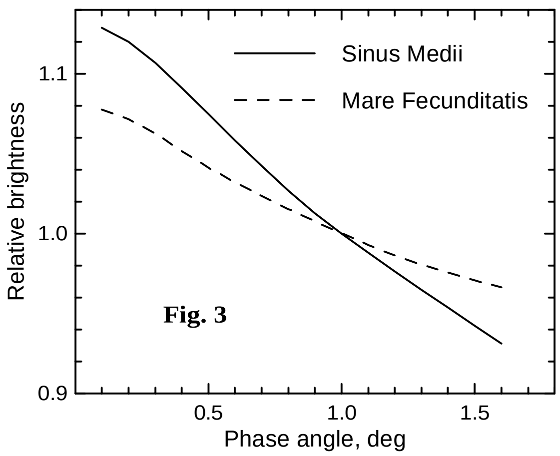

Fig. 3

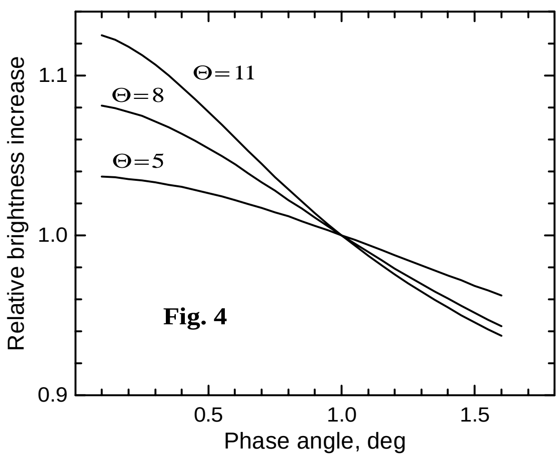

Fig. 4

Accuracy of our estimations of the phase curve for phase angles > ~1.5^0 is lower because the phase curve is less steep, so systematic brightness difference is masked by noise (Fig. 2). The noise can be reduced much more effectively than through simple averaging as we did so far. Common image processing software does not give good results, because the noise originated primarily from the lossy compression, so its statistic noticeably differs from that assumed by common algorithms. Development of specific filters looks very promising.

Contribution of the coherent backscattering enhancement. Unlike [1], we believe that the coherent backscattering enhancement plays a prominent role in the opposition spike observed for the Moon. In the frame of the approach suggested in [3] and [4] the coherent mechanism enhances brightness at the phase angle α by the factor

$$I(\alpha) = 1 + \frac{\exp(-1/\Theta)}{2\sqrt{1+\left(4\pi\,\Theta\,\sin\frac{\alpha}{2}\right)^2}}\,.$$

Parameter Θ is typical size of light spot for regolith medium measured in wavelengths [4]. In other words, Θ is typical distance between entrance and exit point of light ray experienced multiply scattering in the regolith medium, divided by the wavelength. Function $I(\alpha)/I(1^0)$ is plotted in **Fig. 4** for a set of Θ values. It is seen that it is easy to match both amplitude and steepness of the observed opposition spike (Fig. 3) with this function. Thus observed absence of strong and sharp spike does not argue against noticeable contribution of the coherent enhancement.

Strong wavelength dependence of the spike amplitude is wrongly attributed to the coherent enhancement. From one hand, the increase of wavelength decreases Θ (and lessen the spike) just because Θ is something divided by the wavelength. From the other hand, at longer wavelength lunar surface albedo is higher, so the light spot is wider, that implies increase of Θ (and rise of the spike). Balance of these effects for very complex regolith structure is not obvious. Thus the observed weak spectral dependence of the opposition spike does not contradict the coherent enhancement mechanism.

References:

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